5 MS Diodes / Capacitance Name:___________________________

In-Class Problems (today's set takes a bit longer, you might not finish during class!)

(1) For both of the metal-semiconductor junctions shown below

(a) draw the resulting band diagrams after the materials are contacted. Make sure you label the barrier height and the contact potential on your band diagrams, and how each is calculated (in terms of work-functions and electron affinities).

Here is an approach that you might find helpful:

1 –draw some dots at the edge of the metal marking the starting ΔE_C and ΔE_V before we shift the Fermi levels.

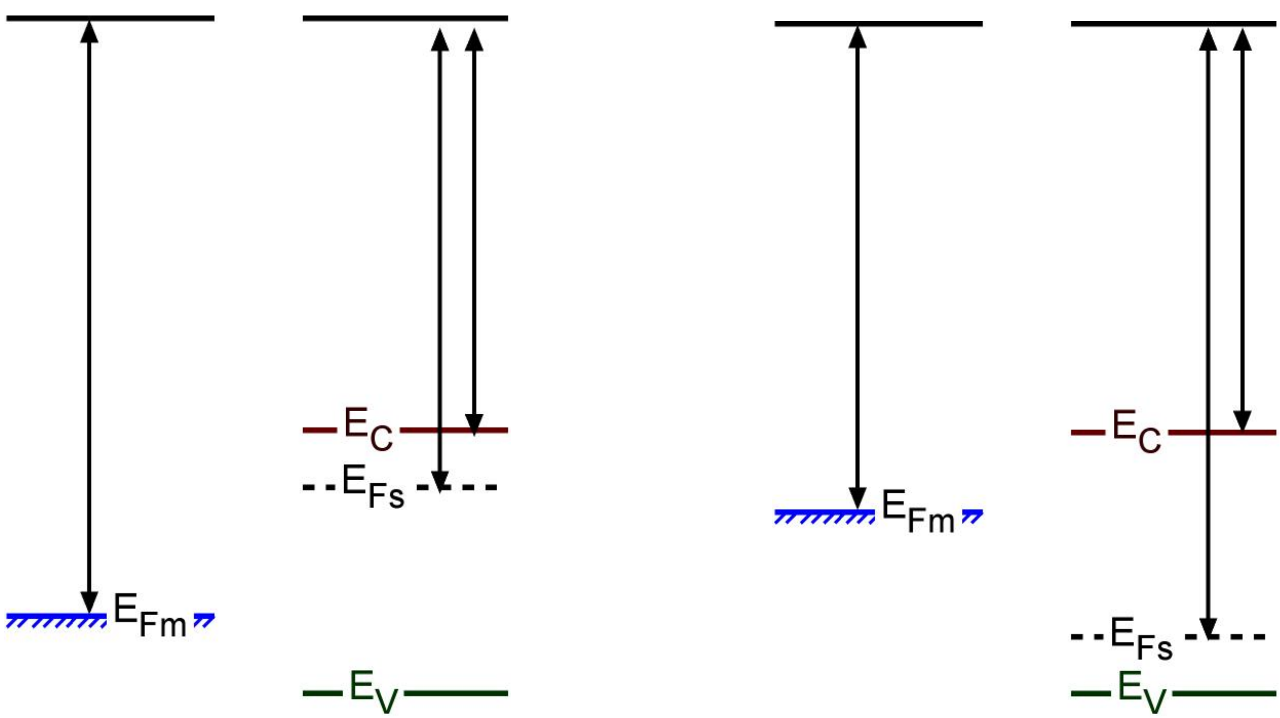
2 – align the Fermi levels (always!) which means you will also have to shift the valence and conduction bands in the semiconductor (but leave some drawing space for the next part)

3 – put in place band-bending to connect the dots to the flat portions of the semiconductor bands. *Remember, when you join two materials, most of the band bending happens on the more lightly doped side (in this case the metal is like 'super doped', tons of carriers, so it's band does not bend at all)*

(b) redraw the diagrams for forward or reverse bias (assume semiconductor is grounded, and you apply + or – voltage to the metal). Also label the currents that dominate for each, and label them as drift or diffusion. Hint: *treat it just like half of a diode, and focus on the semiconductor side (you will notice the metal side faces a barrier, so carriers can only flow from the semiconductor side).*

(c) draw an IV plot for each, and on the plot label the forward and reverse currents as due to electrons or holes. This should be easy once you have done part (b), as it should behave like a diode.

(d) Draw the E-field vs. distance plot for each.



Instructor – Prof. Jason Heikenfeld

(2) Draw a diagram of TWO ways to make an ohmic contact on a n-type semiconductor, and then explain to the Prof. how each works.

(3) Diode capacitance calculations…

(a) A Si pn junction has an area of 100x100 μm^2 and Na=1x10^{17}/cc and Nd=1x10^{15}/cc. Calculate the junction (depletion) capacitance at an applied reverse bias of 4 V. You will need to calculate contact potential also.

(b) What is the depletion width for this capacitance? This is easy if you remember that junction (depletion) capacitance is just the same as the classical capacitor equation.

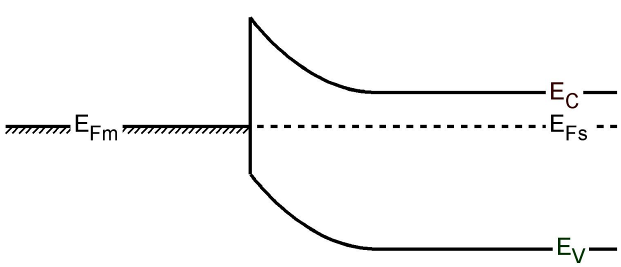
(c) The above questions were related to REVERSE bias where you can use a classical capacitor equation. In FORWARD bias diffusion (storage) capacitance dominates. List below the most basic capacitance equation that describes how capacitance is calculated in forward bias. We covered mentioned this in the lecture…

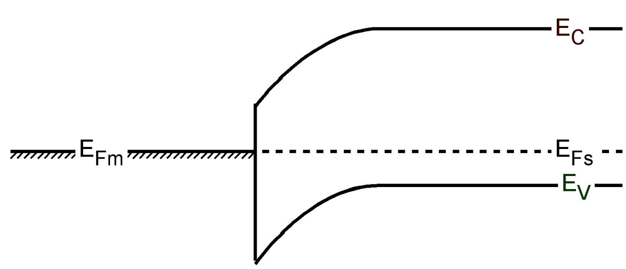
(d) Draw a simple diode I-V plot and diagram on the I-V plot why diffusion (storage) capacitance is zero for a reverse biased diode and why for a forward biased diode it increases exponentially.

(4) Some repetition of what we learned in problem (1). Two metal/semiconductor junctions are given below. For both we ground the semiconductor and apply *negative* voltage to the metal. For both junctions, describe the **<u>type of the current</u>** and **<u>carrier type</u>** that determines the current flow for each case, and **<u>the general magnitude</u>** of the current (large or small). Remember, to solve this:

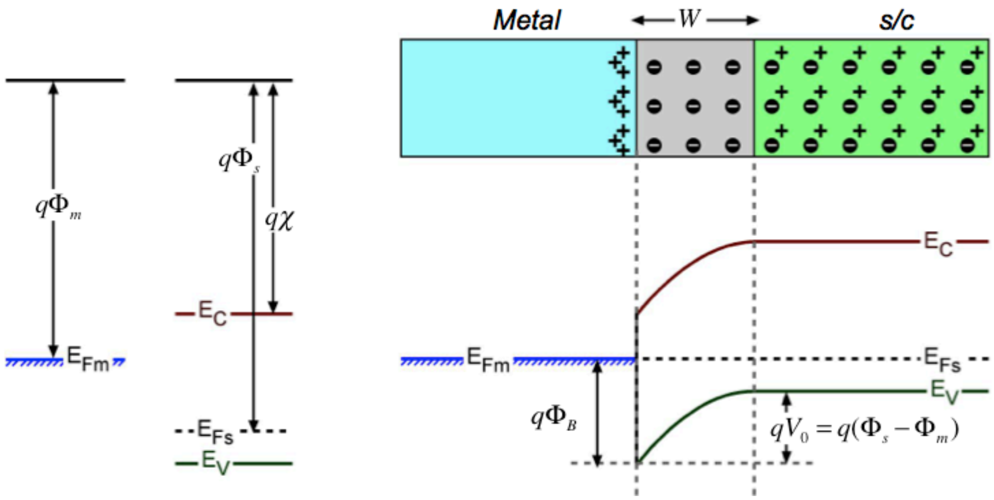
(1) always think of carrier flow from the semiconductor into the metal (the semiconductor determines the flow)

(2) do the conduction band or valence band, each separately, considering if the carriers are majority (lots of current) or minority (small current), if the current flow is due to drift (no change with voltage) or diffusion (large change with voltage)





(5) Consider a metal-semiconductor (Schottky) diode with a p-type semiconductor. This is a tough problem.



(a) How would you calculate reverse bias capacitance for a metal-semiconductor (Schottky) diode with a p-type semiconductor? Give the revised formula as a function of the contact potential for the metal-semiconductor diode. Lets have YOU derive the formula on your own from something we already know…

$$W = \sqrt{\frac{2\varepsilon kT}{q^2}\left(\ln\frac{N_A N_D}{n_i^2}\right)\left(\frac{1}{N_A}+\frac{1}{N_D}\right)}$$

Hint: above is depletion width for a PN junction. This is easy:

(1) replace the part of the equation above that is contact potential, with just Vo

(2) then simplify further considering the metal is like n+++ and the p is therefore the lightly doped side

(3) then use the simple parallel plate capacitor formula to get capacitance!

(b) Well, once you have this formula from (a), you could calculate the capacitance per unit area, if you just knew the contact potential and the doping level… so lets do it!

The electron affinity for most semiconductors like Ge, Si, and GaAs is ~ 4.0 eV. Assume W metal with a workfunction of 4.6 eV is deposited onto Si doped to 10^{18} with Boron. Calculate the contact potential. *Hint: Remember, this doping shifts the Fermi level down (and therefore the semiconductor workfunction), by* $kT \times \ln(N_A/n_i)$. *So 1st, calculate the semiconductor workfunction. Just looking at the diagram, the work function (Phi) should be the electron affinity (Chi), plus ½ the bandgap, plus the amount the Fermi level shifted down from the undoped Fermi level.*

(6) Lets do another diode calculation problem for practice (this is what students struggle with on the first test, especially with what to do w/ kT/q).

An **ideal** Si pn+ junction at 300K has the following parameters (you may or may not need them all).

p-side:	n-side:	General parameters	
Na=10^{15}/cm^3	Nd=10^{17}/cm^3	$\varepsilon_{Si}\varepsilon_0$=1x$10^{-12}$ F/cm	(11.8 x ε_0 F/cm)

reverse saturation current = 4.5x10^{-14} A

a) What are the ideal values for drift (I_{drift}) and diffusion (I_{diff}) currents across the junction at an applied forward bias of +0.7V?

b) What are the ideal values for drift (I_{drift}) and diffusion (I_{diff}) currents across the junction at an applied reverse bias of -2.0V?